ENERGY SAVING

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USE OF ALTERNATIVE ENERGY SOURCES IN THE TECHNOLOGY OF GLASS AND GLASS CERAMIC MATERIALS (A REVIEW)

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The results of using alternative power sources in the technology of glass and glass ceramic materials are described. It is demonstrated that a decorative coating with good physicomechanical, thermal, and consumer properties is formed in the course of plasma-spray deposition of glass powders on household glass articles.

The production of construction materials, including glass, is one of the most energy-consuming sectors of industry [1].

Russia possesses large reserves of oil, natural gas, and coal. However, we are currently witnessing the accelerated development of nuclear and hydraulic power in the whole world, as well as electric power generated on the basis of low-cost coal produced by strip mining. The Word Power Conference, in which the Soviet Union (currently the Russian Federation) has participated since its foundation in 1924, predicts that by 2020 the world energy balance will be shifted toward electricity based on nuclear and hydraulic energy and low-cost coal [2]. The consumption of oil and natural gas will significantly decline due to the high cost of mining and the limited world reserves of this valuable chemical material. Substantial growth in coal mining is predicted, and coal reserves are expected to last for a few centuries. However, extensive universal application of coal and other types of organic fuel may result in environmental pollution with irreversible consequences [3]. Therefore, the problems of searching for alternative energy sources and using them in the glass industry are topical both in our country and abroad.

The importance of this problem is corroborated by the fact that as early as the 1970s the Presidium of the Academy of Sciences of the USSR decreed that the physical chemistry of plasma processes used in technologies for organic and inorganic materials should be included in the list of the USSR's main directions of research and engineering [4]. In the 1980s the Ministry of Construction Materials of the USSR approved a program for the industry titled "The development of technologies and equipment for producing construction materials using nontraditional energy sources."

According to data supplied by Russian researchers, the use of plasma processes is especially effective in the following cases [5, 6]:

– the reaction equilibrium is shifted toward high temperatures;

– the rates of chemical reactions grow substantially with increasing temperature;

– a widely available or not too expensive material is used.

In the 21st century, as in the 1990s of the past century, interest in expanding the application of alternative power sources in glass and glass ceramics technologies has kept on growing. Thus, Russian scientists have develop technologies for synthesis of silicate glasses under the effect of a fast electron beam [7]. The use of this method made it possible to obtain glass with a qualitatively different structure and a different phase composition, more homogeneous with respect to the structural state of iron compared to glasses synthesized according to the traditional technologies [8].

Extensive research in the use of plasma processes is going on in various sectors of industry, including the glass industry. Thus, plasma technology is commonly used in ferrous and nonferrous metallurgy in processing raw materials into metals and in the production of steel and special alloys [9]. Plasma processes are widely used in the development of fine highly refractory glass ceramic coatings on metal and ceramic substrates [10]. Melting of pure high-melting refractory materials has been implemented and is widely used in the technology of ceramics and refractories [11]. The advisability of thermal decoration of wall ceramics and concrete using plasma spray deposition and surface fusion has been

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TABLE 1

Parameter*	Model			
	APR-60	APR-90	APR-91	APR-140
Power, kW	13.2	13.2	25.0	21.9
Arc current strength, A	60	90	90	140
Plant sizes, mm	450 × 400 × 1050	830 × 420 × 820	580 × 420 × 850	1130 × 420 × 1200
Weight, kg	78	120	105	200
Price, USD	2100	3680	3350	6800

* The voltage at 50 Hz frequency is 380 V, the pressure of the plasma-forming gas (air, argon, etc.) is 4 – 6 bar.

demonstrated. Thus, the cost of decorating 1 m^2 of a building facade by plasma fusion of the surface is comparable to the cost of such traditional decoration methods as plastering imitating granite and terrasite, decoration with epoxy paste compositions, or polymer-cement paste treatment with subsequent deposition of fine-grained materials on a fresh layer [12].

The most common method is the synthesis of silicate glass from the vapor phase in a plasma discharge. In this way high-melting high-silica glasses are produced in a high-frequency plasma discharge [13]. The synthesis of quartz glass in a plasma burner is implemented by introducing silicon tetrachloride and titanium in an atmosphere of argon and oxygen. The resulting materials is deposited on a substrate heated to 1300 – 1600°C. Such quartz glass contains 3.9% TiO_2 and has refraction index $n_g = 1.4744$ [13]. Glasses synthesized in a plasma discharge from $SiO_4 – Al(CH_3)_3$ with an Al_2O_3 content of 6.13% have a transformation temperature of 780 ± 30°C and a softening temperature of 960 ± 15°C [14].

The results of treating the edges of a glass sheet using low-temperature plasma are described in [15]. The initial material was sheet glass 5 mm thick preheated to 450°C. This method was recommended for industrial application at the Borskii Glass Works.

The high specific energy concentration in a plasma jet makes it possible to use it for polishing glass products. The polishing of one article (a wine glass, etc.) on the average lasts 3 – 6 sec with the rotational speed of the article equal to 30 – 45 min^{-1}. This technology has been recommended for application at glass factories producing household articles from cut crystal, sodium, and potassium glasses [16].

The synthesis of optical fiber in the vapor phase was performed using low-temperature plasma [17]. However, no less efficient is the synthesis of fiber optics from quartz glass using a plasma burner and powdered silicon oxide as the initial material [18].

One of the promising directions in using low-temperature plasma is producing decorative and protective coatings on glass substrates. Thus, nickel and aluminum oxides were spray-deposited on glass pipes in order to obtain a protective wear-resistant coat [19].

Plasma spraying of glass powders on household glass makes it possible to obtain decorative coatings with good parameters at a lower energy consumption [20].

The implementation of plasma technologies in the industry is expedient for various reasons. First, plasma sets are currently available; second, a plasma gun is a compact unit; third, the price of a plasma gun is quite acceptable.

The comparative characteristics of the plasma guns made by the leading Trafimet European Company are given in Table 1. The Plus and Maxi plasma guns can be used both manually and automatically. As can be seen from Table 1, contemporary plasma guns are sufficiently compact and have a low power consumption.

The main advantage of decorating household glass articles (glasses, wineglasses, vases) by plasma spray deposition of glass powders is its high economic efficiency. This is due to the elimination of manual labor used in such traditional decoration method as hand painting and decalcomania; elimination of the costly and lengthy operation of firing an article to fix a decorative coating produced by traditional methods such as silk-screen printing, aerography, etc., and also due to the lowest currently possible consumption of energy per one glass article. Thus, the decoration of a single glass article lasts a few tens of seconds (5 – 20 sec) with a plasma gun operating power of 12 – 15 kW and a flow rate of the plasma-forming gas equal to 1.5 – 2.0 m^3/h.

An important advantage of plasma spraying is its universality. Virtually any glass powder inclusive of quartz glass with any set of thermal properties can be deposited on the surface of a glass article using the plasma spraying method. Traditional decoration methods, such as silk-screen printing, aerography, decalcomania, or hand painting, only allow for the deposition of low-melting pigments and fluxes, whose temperature of transition from the solid state to the plastic state T_g is no higher than the T_g of the substrate.

In the course of plasma spraying virtually any glass powder with any chemical composition melts in plasma flame under the effect of temperature of the order of 5000 – 10,000 K and is deposited on a cold substrate of the glass article. Thus, the problem of specially developing low-melting decorative glass compositions with a high content of PbO and other expensive components is partly solved. The traditional fluxes and pigments contain scarce and expensive components, such as TiO_2, CaO, B_2O_3, etc. In plasma spray deposition it is possible to use broken and waste tinted glass that is usually sent from a factory to a dumping ground and is not suitable for recycling. The consumer properties of deco-

rative coatings, such as water resistance, acid resistance, microhardness, strength of adhesion to the substrate, and heat resistance are significantly improved as well.

We have studied the effect of the method of plasma spraying of glass powders on the physicomechanical, thermal, and consumer properties of glass products. The articles to decorate were a wine glass and a liqueur glass serially produced at the Krasnyi Mai glass factory. The glass powder used for decoration was based on milky household glass and had the following chemical composition (wt.%): 66.6 SiO_2, 6.3 Al_2O_3, 6.3 CaO, 14.8 Na_2O, 1.0 K_2O, and 5.0 F.

A standard UPU-8M plasma gun with a GN-5r plasma burner was used. Before decoration the glass surface was degreased with a cotton tampon impregnated with acetone or ethanol, and then a template made of copper or aluminum foil was applied to the glass article. The article was placed on a rotating tournette and the glass powder was deposited by spraying. The operating power of the plasma gun was 15 kW. The plasma-forming gas was argon consumed at the rate of 1.8 m^3/h. The decoration of one glass article lasted 5 – 10 sec depending on the configuration and the surface area of the deposited pattern.

After decorating, the main quality parameters were determined according to the GOST 30407 requirements.

Quality parameters of finished glass articles

Decorative coating thickness, nm	100 – 200
Water resistance of decorative coating, hydrolytic class	III
Acid resistance of decorative coatings, grade	5 (no variation in tint and luster)
Heat resistance, °C	
of decorative coating	122
of the glass article	90 – 70 – 20
Microhardness, MPa	5800
Strength of adhesion of decorative coating, MPa	18.2
Stress in the article, MPa	2.03

As can be seen, the decorative plasma coatings meet the standard requirements. Plasma spraying of glass powders on a glass substrate produces a decorative coating with good physicomechanical, thermal, and consumer properties. This makes it possible to recommend the use of low-temperature plasma in glass and glass ceramic technology, in particular, for depositing decorative coatings.

Thus, alternative power sources can be effectively used in the technology of glass and glass ceramic materials.

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